Prototyping a Low-Cost, Low-Power System for Automated Monitoring of Nocturnal Insects

Jonas Beuchert
Biodiversity Science Area
UK Centre for Ecology & Hydrology
Crowmarsh Gifford, Oxfordshire, UK
https://orcid.org/0000-0003-1463-2853

Abstract*—High-resolution cameras combined with powerful attracting light sources and machine-learning-based processing pipelines are a novel approach to monitoring of nocturnal insects. They enable automated monitoring of insects in contrast to manual trapping and identification of insects by human experts. However, only a few hardware systems capable of automated monitoring of insects exist and they usually require expensive components, complex manufacturing, and heavy batteries. A reason for this is that they are commonly based on a single-board computer combined with additional off-the-shelf hardware. This lacks power efficiency, increases component costs, and requires extensive manual wiring. In contrast, this paper presents a system that employs custom-made hardware tailored to the specific use case. It is built around a microcontroller instead of a single-board computer and all components are placed on two printed circuit boards rather than wired together. This significantly lowers manufacturing and component cost, the weight and size of the system, as well as the power consumption. The resulting system decreases costs by about 90% and can operate for a night on a consumer-grade power bank. An accompanying app improves usability, opening the door for usage by non-experts, e.g., citizen scientists and hobbyist moth trappers.

I. Introduction / Background

Insects are not only of interest for lepidopterists, but also, for example, for ecologists who study biodiversity and ecosystem health and the impact of external factors such as farming, climate change, and land management on those. This is because insects are a good indicator for biodiversity since they respond quickly to environmental changes, provide large sample sizes, and play an important role for pollination and in the food chain. Crucial scientific insights and indicators can be inferred from the overall abundance of insects as well as the distribution of individuals among species as well as the change of both over time. Traditionally, nocturnal insects are caught in so-called moth traps, which are often lethal, and then classified by experts. However, this is time consuming and prevents monitoring at spatial and temporal scale. That is why – with the advent of machine learning and computer vision – researchers started using camera traps paired with attractive lights to monitor nocturnal insects. A powerful light source emits light of carefully selected wavelengths to attract insects at night. The insects land on an illuminated white board. Next, a camera takes pictures of the insects on the board. Usually, the images are stored locally. If paired with batteries and a power source such as a solar panel, such an automated insect monitoring system can autonomously collect data for months. Afterwards, the data is transferred to a server where machine learning algorithms automatically identify, count, and classify the insects.

II. Related Work

Fig. 1. Existing research-grade AMI system for automated monitoring of insects. It has a light to attract insects (top), a camera to take photos (right), and a big battery (bottom). Dozens of AMI system have been deployed around the world, but they are expensive and bulky. © UKCEH.

Existing automated monitoring systems for nocturnal insects including the DIOPSIS (Digital Identification Of Photographically Sampled Insect Species) [1], the Mothbox [2], and the AMI (Automated Monitoring of Insects) system [3] (Figure 1), which is developed from the AMT (Automated Moth Trap) [4]. Both, the DIOPSIS and the AMI system, are large research-grade devices, which combine solar panels, large batteries, a high-resolution camera, and lights in a robust housing that can be deployed for months in the field. The AMI system is open-source and costs a few thousand pounds. The DIOPSIS unit has probably at least similar costs. The Mothbox is a smaller system that is still under development, open-source, costs a few hundred pounds, and targets individuals interested in a DIY solution. The AMI system and the Mothbox are designed around a single-board computer and the DIOPSIS likely too.

III. Existing Prototype

Several early-stage prototypes of the proposed system have been built. This section describes the electronics, the housing, and the software that they have in common.

A. *Electronics*

Fig. 2. Printed circuit board with cut-out for camera surrounded by light emitting diodes (LEDs) for illumination of the insect landing board. The microcontroller is visible below. © Jonas Beuchert, UKCEH.

The system described in this paper is built around a low-power, low-cost microcontroller, see Figure 2. It is powered from a power bank, a USB charger, or potentially another source, like a USB solar panel. The microcontroller maintains a real-time clock (RTC) and wakes up and switches on lights according to a user-defined schedule. The system has two sets of lights. Firstly, a set of high-power LEDs with different wavelengths placed together with a current regulator on a separate printed circuit board (PCB). This light attracts insects during night from distance. Secondly, a set of white mid-power LEDs is placed on the same PCB as the microcontroller and illuminates a white wooden board that serves as a landing area for the insects. In regular intervals, the microcontroller activates a camera to take a picture of the board and writes it to memory in a compressed file format, JPEG. At any other time, the camera is powered off to save energy.

Optionally, a microphone or a module for wireless connectivity can be attached to the PCB, too, allowing the recording of bird sound and the wireless transmission of status information, respectively.

B. *Housing*

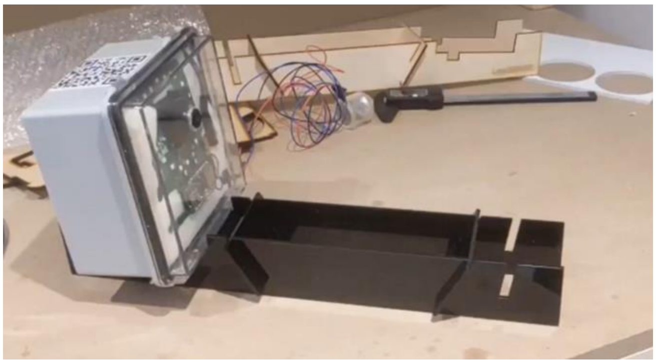

Fig. 3. Prototype in its weather-proof housing on a laser-cutted stand. © Tom August, UKCEH.

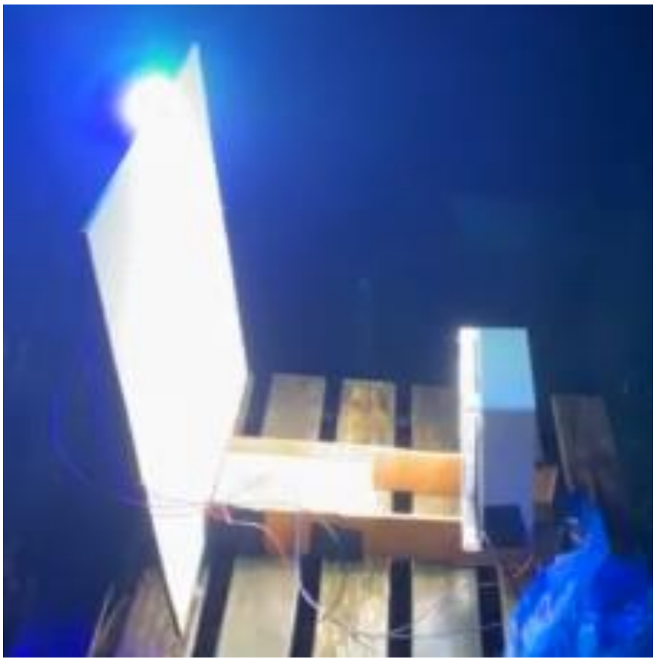

Fig. 4. Prototype operating at night. Landing board with attractive light on the left, main printed circuit board with camera and additional lights on the right. © David Roy, UKCEH.

Fig. 5. Moth on landing board captured by the camera of the prototype. © UKCEH.

The prototype is housed in a weather-proof box with a transparent lid in fixed distance to a wooden board covered by white marine paint, see Figures 3, 4, and 5. The box and the wooden board are connected via a detachable rig made of four laser-cutted parts. The attractive light is mounted on top of the board in a UV-transparent plastic tube and connected to the main PCB via three insulated wires.

C. *Software*

Users configure the device via USB using a cross-platform progressive web app (PWA). It can run in a browser window, but also as native app. Additionally, PWAs load quickly, require little memory, are secure to use, and a service worker automatically keeps the app up-to-date. The app communicates with the microcontroller via WebUSB using a JavaScript interface, thus not requiring any driver installation.

IV. Responsible Innovation

Ideally, the system will help researchers, landowners, and citizen scientists to better understand their environment and to make informed decisions to improve biodiversity.

In contrast to existing systems, the described innovation minimises the number of components, especially regarding batteries, and, therefore, reduces the overall environmental footprint. In addition, in aims to be a more accessible system, by being more affordable and easier to use.

V. Author bio / experiences

I am a scientist at the UK Centre for Ecology & Hydrology (UKCEH) based in Oxfordshire. Developing wildlife monitoring technology is the focus of my work, currently camera traps. For this, I collaborate with a number of researchers from different fields at my institute and beyond to develop technology that is innovative, but also the best fit for its purpose. My personal interest lies in wildlife monitoring technology that is scalable, affordable, and accessible.

Before I started to work at UKCEH in 2023, I completed a DPhil in the Department of Computer Science at the University of Oxford where I designed hardware and software for low-cost, low-power, open-source wildlife tracking [5]. My bachelor's and master's degrees are both in electrical engineering and from TU Berlin. During this time, I picked up a wide range of skills, including PCB design, wireless communication, firmware development, signal processing, optimisation, and web development.

VI. Acknowledgements

The project is funded by the UK Centre for Ecology & Hydrology (UKCEH) and based on an idea of Tom August, David Roy, and others.

VII. References

[1] "DIOPSIS camera," website, https://diopsis.eu/en/camera/, accessed on 23 May 2024.

[2] A. Quitmeyer, "Mothbox," GitHub repository, https://github.com/Digital-Naturalism-Laboratories/Mothbox, accessed on 23 May 2024.

[3] UK Centre for Ecology & Hydrology, "UKCEH AMI system," website, https://www.ceh.ac.uk/solutions/equipment/automated-monitoring-insects-trap, accessed on 23 May.

[4] K. Bjerge et al., "An automated light trap to monitor moths (lepidoptera) using computer vision-based tracking and deep learning," Sensors 2021, 21, 343. https://doi.org/10.3390/s21020343

[5] J. Beuchert, "Probabilistic snapshot GNSS for low-cost wildlife tracking," DPhil thesis, University of Oxford, 2023. http://dx.doi.org/10.5287/ora-dae7ap229